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(54) Phased array antenna management system and calibration method

System zur Steuerung einer phasengesteuerten Gruppenantenne und Verfahren zur Eichung

Système pour commander un réseau d'antennes à commande de phase et procédé de calibration

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[0001] The present invention relates to a phased array antenna management system for use with a phased array communication system comprising a phased array antenna that includes a plurality of antenna lement chains, wherein each chain comprises a phase adjustment network, an amplifier, a filter, and an antenna element,

a probe carrier source for generating a probe carrier signal that is processed by each antenna element chain, and
means for generating and applying corrective weighting coefficients to the phase adjustment networks.

[0002] Further, the present invention relates to a method of calibrating a phased array antenna of a phased array communication system, the phased array antenna having a plurality of antenna element chains, comprising the steps of:

processing a probe carrier through the antenna and
generating and applying corrective weighting coefficients to the antenna element chains.

[0003] Such a phased array antenna management system and such a method of calibrating a phased array antenna are known from GB-A-2 262 386.

[0004] The present invention relates generally to phased array communication systems, and more particularly, to a phased array antenna management system and antenna calibration method for use with a phased array communication system.

[0005] Increasing system performance requirements placed on future communications satellite systems, for example, require the application of active phased array technology either as a complete antenna or as a feed for a reflector type antenna system. Active phased arrays include passive antenna radiating elements and associated chains of electronic elements including amplifiers, filters and frequency translators. Each of these components is subject to individual transfer function variation, or failure, over a mission's life.

[0006] Using conventional approaches, these effects are minimized by designing each component in an element chain to closely track all of the other chains over the full range of environment and life. In high performance systems, tight tracking performance is a major cost driver. In addition, unforeseen component changes can result in uncompensatable system degradations. The conventional approach for addressing component failure is to include a sufficient number of redundant components. Detection and identification of a failed element chain may not always be practical for satellite payloads. Also, fault detection circuitry can add significant cost and complexity to the design.

[0007] A further weakness of conventional approaches applicable to space systems, is potential degradation due to initial system deployment imperfections. One example of this is a mechanical misalignment between different sections of a multi-panel phased array. Potential system performance degradation therefore results since calibration and compensation at an individual element level is impractical.

[0008] From the above-mentioned document GB-A-2 262 386 a phase measurement circuit of a phased array antenna having both transmitting and receiving functions includes a plurality of antenna elements, phase shifters disposed corresponding to the antenna elements to form a beam in a desired direction by changing the phase value, a control circuit for controlling the phase shift quantity of the phase shifters, a test antenna for receiving electric waves from the phased array antenna and for transmitting a test signal to each element of the phased array antenna. The test antenna may be incorporated in the phased array. The phase shift quantity of each of the phase shifters is adjusted to the value where the test signal attains the maximum value.

[0009] A similar method of adjusting the phase shifters of a phased array antenna is known from document US-A-5,027,127, wherein additionally the amplitude of each element in the antenna array is corrected.

[0010] From EP-A-0 642 101 (comprised in the state of the art according to Art. 54 (3) EPC) a digitally controlled beamformer for a spacecraft is known which includes means for periodically calibrating the feed paths of the spacecraft antenna array by measuring the apparent movement of the center of a reference signal and a nominal signal and utilizing the measured data to compensate for at least the phase shift in the antenna feed paths. The measured data may also be used to compensate for amplitude and phase shift in the antenna feed paths.

[0011] Thus, it is an object of the present invention to provide a management system and calibration method for use with a phased array communication system that overcomes the limitations of conventional approaches for controlling component failures.

[0012] The above objective is achieved by the phased array antenna management system, mentioned at the outset, wherein said probe carrier source generates a non-interfering carrier signal, the communication system comprises transmit and receive phased array antennas that each include a plurality of antenna element chains, each chain includes additionally an amplitude adjustment network and has a desired amplitude and phase relationship with respect to the other chains of each of the antennas, the probe carrier signal is orthogonally processed by each antenna element chain, determining means determine the amplitude and phase produced by each chain of the transmit and receive

phased array antennas in response to the probe carrier signal, for comparing the amplitude and phase produced by each chain to the desired amplitude and phase relationship for each chain, and for generating the corrective weighting coefficients for chains that do not have the desired amplitude and phase relationship, and applying means apply the corrective weighting co ffici nts to the amplitude and phase adjustment networks of each chain of the transmit and receive phased array antennas to produce the desired amplitude and phase relationship thereb tween.

[0013] Further, the above objective is achieved by the calibrating method, mentioned at the outset, wherein the communication system has transmit and receive phased array antennas, each of the antenna element chains has a desired amplitude and phase relationship with respect to each other, a non-interfering probe carrier is orthogonally processed through each antenna chain of the transmit and receive antennas, the respective phases and amplitudes of the processed probe carriers are compared to provide a map of differential amplitudes and phases of each antenna chain of the respective transmit and receive antennas, the corrective weighting coefficients are generated for chains that do not have the desired amplitude and phase relationship, and the corrective weighting coefficients are applied to each chain of the transmit and receive antennas to produce the desired amplitude and phase relationship therebetween.

[0014] Generally, the present invention provides for a phased array antenna management system and method for use with a phased array communication system. The phased array communication system comprises transmit and receive phased array antennas that each include a plurality of antenna element chains, wherein each chain comprises an amplitude adjustment network, a phase adjustment network, amplifiers, filters and frequency translators, as required, and an antenna element. Each chain has a desired amplitude and phase relationship with respect to the other chains of each of the antennas. The system comprises a probe carrier source for generating a probe carrier signal that is orthogonally processed by each antenna element chain. Means is provided for determining the amplitude and phase produced by each chain of the transmit and receive phased array antennas in response to the probe carrier signal, for comparing the amplitude and phase produced by each chain to the desired amplitude and phase for each chain, and for generating corrective weighting coefficients for chains that do not have the desired amplitude and phase. Means is provided for applying the corrective weighting coefficients to the amplitude and phase adjustment networks of each chain of the transmit and receive phased array antennas to produce the desired amplitude and phase relationship therebetween.

[0015] A method of calibrating transmit and receive phased array antennas of a phased array communication system, wherein respective antenna element chains comprising each of the antennas have a desired amplitude and phase relationship with respect to each other comprises the following steps. A noninterfering probe carrier is processed through each antenna chain of the transmit and receive antennas. The respective phases and amplitudes of the processed probe carriers are compared to provide a map of differential amplitudes and phases of each antenna chain of the respective transmit and receive antennas. Corrective weighting coefficients for chains that do not have the desired amplitude and phase are generated. The corrective weighting coefficients are then applied to each chain of the transmit and receive antennas to produce the desired amplitude and phase relationship therebetween.

[0016] The present invention provides for a phased array antenna management system and calibration method that may be employed with a phased array antenna, and which increases robustness of the phased array antenna to component changes or failures. Phased array antennas are subject to performance degradation due to mistracking between active and passive components making up individual chains that form the array. The present invention employs a system level measurement, conducted during normal operation, to determine on an element by element basis, the actual tracking performance of each individual chain. This information is then employed to compensate the each chain for the measured error. The present system does not require interruption of service to perform its function.

[0017] The present invention provides for the integration of various components into a novel phased array antenna management system. The phased array antenna system comprises a plurality of parallel radiating element chains that operate in phase to meet overall performance requirements of the system. A means and method for measuring the real-time performance (amplitude and phase) of individual elements utilizing added test (calibration) carriers is provided by the present invention. An earth calibration station or a processor onboard the satellite employs an algorithm for determining required correction coefficients for each chain, and a means for compensating individual element chain for errors in amplitude and phase are also provided.

[0018] The present invention improves on the shortcomings of conventional approaches. A nondisturbing measurement process is performed to characterize the performance of the transmit and receive antenna arrays. The system generates a noninterfering probe RF carrier that is applied to each element chain of an antenna array simultaneously with the normal signal waveform. The probe carrier is sufficiently small (narrow bandwidth, low power, encoded, or outside the utilized frequency band) so that it does not significantly degrade system operation. The relative amplitude and phase of the probe carrier, as applied to an element chain, is accurately measured at an receiving terminal. By switching the probe carrier, in time sequence, between multiple element chains, for example, the differential amplitude and phase characteristics of each of the array elements is determined. This process also serves to detect component failures in each chain. Each chain includes a commandable amplitude and phase weighting network. The desired

amplitude and phase differential relationships are determined by antenna beam pointing and shaping requirements. Element to element mistracking, how v r, modifies the required weighting commands. Once th differential amplitude and phase tracking characteristics of the operating antenna are characterized, the individual weighting networks are commanded to settings that compensate for the measured values.

[0019] The present system provides an accurate measurement of real-time system performance. Since variations in individual chains can be compensated over the life of a mission, the requirements for individual component tracking accuracy are reduced. This provides a significant cost saving. In the event of element failure, the present system permits the array to be reoptimized to minimize the performance impact of the failure. The present invention thus uses the system to solve component level problems, such as those occurring in the transmit and receive antenna chains of the transmit and receive phased array antennas.

[0020] The present invention may be employed with satellites incorporating active phased array antennas, such as mobile satellite systems including AMSC, INMARSAT P21, REGIONAL ASIA MOBILSAT, and AFRICOM, for example.

[0021] The various features and advantages of the present invention may be more readily understood with reference to the following detailed description taken in conjunction with the accompanying drawings, wherein like reference numerals designate like structural elements, and in which:

Fig. 1 illustrates a typical phased array-based communications satellite system employing a phased array antenna management system in accordance with the principles of the present invention;
Fig. 2 illustrates details of the transmit phased array antenna and the operation of the phased array antenna management system of Fig. 1; and
Fig. 3 is a flow diagram that illustrates a calibration method in accordance with the principles of the present invention.

[0022] Referring to the drawing figures, a typical phased array-based communications satellite system 10 is shown for illustrative purposes with reference to Fig. 1 that employs a phased array antenna management system 20 and calibration method 50 in accordance with the principles of the present invention. The communications satellite system 10 is comprised of a plurality of user mobile terminals 11, a satellite 12, a gateway hub station 13, and a calibration station 14. A mobile communications link 15 from the satellite 12 to the user mobile terminals 11 is provided at S band, for example, while a gateway communications link 16 from the satellite 12 to the gateway hub station 13 is at Ka band, for example. The S band mobile communications link 15 is also used to provide communications between the calibration station 14 and the satellite 12.

[0023] As shown in Fig. 1, the satellite 12 comprises a transmit (forward) phased array antenna 21, and a receive (return) phased array antenna 22, that service the mobile communications link 15 between the calibration station 14, the satellite 12 and the mobile terminals 11. A feeder antenna 23 that operates at Ka band, for example, is provided that may use a gimbaled reflector, for example, to service the gateway communications link 16 between the satellite 12 and the gateway hub station 13. A transmit link payload 25 and a receive link payload 26 are respectively coupled between the transmit and receive phased array antennas 21, 22 and the feeder antenna 23 by way of a power splitter 24. A transmit and receive link payloads 25, 26 comprise control and processing electronics and maneuvering systems required for operation of the satellite 12.

[0024] With regard to both the transmit and receive paths (feeder antenna 23, power splitter 24, receive link payload 26 and receive phased array antenna 22; feeder antenna 23, power splitter 24, transmit link payload 25 and transmit phased array antenna 21), a phased array beam forming function is performed on the satellite 12 by a digital processor 18, or controller 18, that forms part of the respective transmit and receive link payloads 25, 26. The amplitude and phase control function performed by the processor 18 is routine in the art and will not be described in detail herein. Signals are provided by the controller 18 that independently control the amplitude and phase drive to each of the array elements 28 of the transmit and receive phased array antenna 21, 22 in response to signals generated by the system 20 and method 50. The processor 18 may also perform processing necessary to compute correction terms in accordance with the present method 50.

[0025] The various specific embodiments of the present invention that are detailed below typically depend upon where correction factors are computed, for example. For example, in one embodiment, signals are transmitted from the satellite to the calibration station 14 to calibrate the transmit path while signal are transmitted from the calibration station 14 to the satellite 12 to calibrate the receive path. If a self-contained system 20, is employed, a local sense antenna 17 is used to sample outputs of the transmit antenna elements which are fed back to the processor 18 which computes the corrective weighting coefficients. The self-contained system 20 constitutes a closed loop system 20 with no human intervention, in that the error measurements directly control the corrections. Such a closed loop system 20 may also be implemented with a remote earth station as well as the onboard local sense antenna 17. Similarly, a local signal source is used in the closed loop system 20 to provide a calibration signal that is processed through the receive antenna 22 to the processor 18 which computes th corrective weighting coefficients for the receive path.

[0026] Fig. 2 shows details of th transmit and receive phased array antennas 21, 22 and illustrates the operation of phased array antenna management systems 20 of th present invention. The transmit and receive phased array antennas 21, 22 are comprised of a power splitter 31 having an input coupled to receive signals by way of the feeder antenna 25 and whos outputs are coupled through a plurality of element chains 30 of the transmit phased array antenna 21 to the respective antenna elements 27 thereof. Each chain 30 is comprised of a commutator switch 33, amplitude adjustment network 34, phase adjustment network 35, an amplifier 36 and a bandpass filter 37 to the respective antenna elements 27. A probe carrier source 32', such as an oscillator 32', for example, is coupled to each switch and is employed to generate a probe carrier used to implement antenna calibration performed by the phased array antenna management system 20. The processor 18, which also functions as a controller 18, is coupled to the commutator switch 33, amplitude adjustment network 34, and phase adjustment network 35 of each chain in order to perform a phased array beam forming function provided by the phased array antenna management system 20. The processor 18, or controller 18, is coupled to a receiver and demodulator 41', 42' that are coupled to an antenna 47. The processor 18, or controller 18, is also used to apply corrective weighting coefficients to the amplitude and phase adjustment networks 34, 35 to calibrate the receive phased array antenna 22 during this phase of calibration.

[0027] The phased array antenna management system 20 provides for separate calibration of the forward and return link phased arrays antennas 21, 22. In each case a center element 27', for example, of each antenna 21, 22 is designated as a reference element 27'. It is to be understood that the "center element" need not be a center element of the antenna in a physical sense. In the forward direction, a small unmodulated probe carrier generated by the probe carrier oscillator 32' is alternately radiated from the reference element 27' and a second element 27 under test. The probe carrier is generated and alternately applied to the drive signals for each element 27', 27 using the digital processor 18. The respective probe carrier signals are transmitted by way of the mobile communications link 15 to the calibration station 14.

[0028] The calibration station 14 comprises processing means 40 for determining the amplitude and phase produced by each chain 30 of the transmit and receive phased array antennas 21, 22 in response to the probe carrier signal. The processing means 40 comprises an antenna 46, a receiver 41, amplitude and phase demodulator 42, and amplitude and phase measurement circuitry 43 for generating amplitude and phase corrective weighting coefficients ΔA $\Delta\phi$. The calibration station 14 also comprises a probe carrier source 32, such as a local oscillator that is modulated by a code generator, for example, for generating probe carrier signals. Alternatively, respective probe carrier signals are transmitted to the antenna 17 whose output is fed back by way of the receiver 41' and demodulator 42' (substantially the same as the receiver 41 and demodulator 42 at the calibration station 14) to the processor 18 for computation and/or application of corrective weighting coefficients to the respective antenna element chains 30.

[0029] When the probe carrier transmitted by the reference element 27' and element 27 under test is received at the calibration station 14, the phase and amplitude of the two signals are compared. Repeating this process for each of the elements 27 of the transmit phased array antenna 21 provides a map of the differential amplitudes and phases of each element 27 thereof. Calibration of the transmit phased array antenna 21 is performed in well under two minutes.

[0030] In the return direction, the process is reversed. A small unmodulated S band probe carrier is radiated from the calibration station 14. The S band probe carrier is received by all of the array elements 28 of the receive phased array antenna 22, but only two elements 28 are alternately sampled to form a calibration carrier. The calibration carrier is downlinked at Ka band to the gateway hub station 13 where their amplitudes and phases are compared. The probe carrier is sufficiently small (narrow bandwidth, low power, or encoded, etc.) so that it does not create unacceptable interference with normal communications traffic communicated by the system 10.

[0031] Optimum performance of the transmit and receive phased array antennas 21, 22 requires that each of the array element paths or chains 30 provide the proper phase and amplitude weighted signals. While each of the components of the element chains 30 is designed and implemented to provide transfer function stability over the lifetime of a mission, periodic recalibration of the phased array antennas 21, 22 using the principles of the present invention insures peak performance. In addition, failures of any element chain 30 are quickly detected and accurately characterized to permit remedial action, if necessary. The performance of these measurements do not interrupt the normal flow of communication signals by the system 10.

[0032] The following description describes a specific system link budget for a system that uses digital processing. It is to be understood that this is an example for illustrative purposes only, and is not to be considered as generic for all systems.

[0033] The measurement accuracy of the phased array antenna management system 20 is determined by the signal to noise ratio and the measurement averaging time. For a typical system, by reducing the measurement bandwidth to 100 Hz, good accuracy and measurement speed is attained without undue system resource demands, as is illustrated with reference to Tables 1 and 2.

TABLE 1

PERFORMANCE BUDGET HYPOTHETICAL MOBILE SATELLITE SYSTEM [Forward Direction]		
	Center [REF] Element	Edge Element
RF element power [272 RF Watt array total]	+42 dBm	+25 dBm
Element antenna gain	+12 dB	+12 dB
Element EIRP	+54 dBm	+37 dBm
Path loss [10,600 KM, f= 2 GHz]	-179 dB	-179 dB
Receive earth terminal G/T [10' Dia., 100 °K]	+13 dB/°K	+13 dB/°K
C/T	-142 dB W/K	-159 dB W/K
C/N [1 Hz BW]	+86.6 dB Hz	+69.6 dB Hz
If probe carrier is -10 dB relative to edge element power:		
C/N [100 Hz]	+39.6 dB	+39.6 dB
The 1 sigma amplitude accuracy is:		
20 Log[1 + 0.707 * 10^ -(C/N/20)]	0.09 dB	0.09 dB
The 1 sigma phase accuracy is:		
Arctangent [0.707 * 10^ -(C/N/20)]	0.6 Deg	0.6 Deg
Time for single element measurement	50 mSec	50 mSec

TABLE 2

PERFORMANCE BUDGET HYPOTHETICAL MOBILE SATELLITE SYSTEM [Return Direction]		
	Center [REF] Element	Edge Element
Earth terminal transmit power	-15 dBm	-15 dBm
Earth terminal antenna gain	+33 dB	+33 dB
Terminal EIRP	+18 dBm	+18 dBm
Path loss [10,600 KM, f = 2 GHz]	-179 dB	-179 dB
Array element G/T [12 dB gain, T = 67 Deg]	-6.3 dB/°K	-6.3 dB/°K
C/T	-163 dBW/K	-163 dB W/K
C/N [1 Hz BW]	+61.3 dB Hz	+61.3 dB Hz
C/N [100 Hz BW]	+41.3 dB	+41.3 dB
The 1 sigma amplitude accuracy is:		
20 Log[1 + 0.707 * 10^ -(C/N/20)]	0.05 dB	0.05 dB
The 1 sigma phase accuracy is:		
Arctangent [0.707 * 10^ -(C/N/20)]	0.35 Deg	0.35 Deg
Time for single element measurement	50 mSec	50 mSec

[0034] In the forward direction, antenna clement chain 30 calibration is performed by alternately injecting the probe carrier onto the reference element 27' and the element 27 under test. The probe carrier is thus radiated from alternating elements of the phased array antenna 21 and received at the calibration station 14 as a TDM signal. In the return direction, the calibration process is reversed. The probe carrier radiated from the calibration station 14 is received by all of the elements 28 in the receive phased array antenna 22. The received signal from the reference element 27' and the element 28 under test is alternately sampled in the processor 18, and the resulting waveform constructs a narrow band calibration carrier. This carrier is downlinked to the gateway hub station 13 on the gateway communications link 16. Demodulation at the calibration station 14 provides calibration parameters. For forward link calibration, the probe carrier, represented by digitally encoded samples, is generated in the processor 18. The probe carrier samples are digitally added to the communications signal bit stream destined for a single array element 27. A subsequent digital to analog conversion process creates an analog version of the probe carrier along with the normal communication signals for that element 27. The probe carrier is alternated between elements 27', 27 by switching the probe samples between their respective element adders_.

[0035] In the return direction, the unmodulated S-band carrier is radiated from the calibration station 14. Th received probe carrier is alternately selected from the reference lement 27' and the element 28 under test. The bit stream

resulting from the analog to digital conversion process on each array element 28 includes the ground originated probe signal. The bit stream from each of the elements 28 is selected by th commutator switch 33 to creat a tim -multiplexed bit stream. This bit stream, after digital to analog conversion, serv s as the return direction calibration probe carrier. The switched waveform is downlinked to the calibration station 14 for comparative measurement. After downlinking, the probe carrier signal is filtered out of the calibration carrier using a 100 Hz bandwidth filter, for example. Once the differential amplitude and phase of each of the elements has been measured, a computational comparison with the desired amplitude and phase distribution is performed at the gateway hub station 13. The amplitude and phase weighting networks 34, 35 under control of the processor 18 are commanded to values that compensate for the measured errors.

[0036] The calibration method 50 in accordance with the present invention will be more clearly understood with reference to Fig. 3 which is a flow diagram illustrating a calibration method 50 in accordance with the principles of the present invention. The calibration method 50 comprises the following steps. In the transmit direction, a noninterfering and preferably nonburdening carrier signal is generated, indicated by step 51. Each element chain processes carrier in an orthogonal manner, whereby the signals processed by each chain are sequentially processed in time, or frequency, or have distinct orthogonal codes so that each chain is distinguishable, indicated by step 52. The carrier signal is transmitted by the transmit phased array antenna 21, indicated by step 53. The orthogonal carrier signals derived from each chain are then detected at a remote location, indicated by step 54. The remote location may be the calibration station 14 or the local antenna 17 located disposed on the satellite 12. The amplitude and phase transmitted by each of the antenna element chains is then measured, indicated by step 55. The amplitude and phase of each of the chains is compared to the amplitude and phase of a center chain, indicated by step 56. Corrective weighting coefficients are then generated in response to the measured amplitude and phase signals derived from each of the chains, indicated by step 57. Once the corrected weighting coefficients have been computed, they are applied to the amplitude and phase weighting circuits 34, 35 by the controller 18, indicated by step 58.

[0037] In the receive direction, a noninterfering and preferably nonburdening carrier signal is generated at either on the satellite 12 or at the calibration station 14, indicated by step 61. The carrier signal is transmitted to the receive phased array antenna 22, indicated by step 62. The signals that are received and processed by each element chain are detected in an orthogonal manner, whereby the signals derived from each chain are sequentially processed in time, or frequency, or have distinct orthogonal codes so that each chain is distinguishable, indicated by step 63. The orthogonal carrier signals derived from each chain are then detected to generate amplitude and phase signals for each chain, indicated by step 64. The amplitude and phase of each of the chains is compared to the amplitude and phase of a center chain, indicated by step 65. Corrective weighting coefficients are then generated in response to the measured amplitude and phase signals derived from each of the chains, indicated by step 66. Once the corrected weighting coefficients have been computed, they are applied to the amplitude and phase weighting circuits 34, 35 by the controller 18, indicated by step 67.

[0038] In general, the amplitude and phase signals associated with the chains have a known relationship with respect to each other, and if they do not, as determined by the measured amplitude and phase data derived from processing the calibration signals, then corrective weighting coefficients are generated to correct the outputs of the chains. The corrective weighting coefficients may be used to correct for drift or for catastrophic failure of any of the chains. In the case of drift, offsets are generated that correct chains whose amplitude and phase are not at their proper values. In the case of failure of a chain, the balance of the chains are reconfigured by adjusting each of the amplitudes and phases thereof to generate a desired beam profile from the transmit phased array antenna 21. The weighting may be accomplished by adjusting physical circuits, such as the amplitude and phase weighting circuits 34, 35, or by applying mathematical coefficients that are applied in software, for example, such as in the processor 18, in a manner generally well known in the art. The calibration method 50 may be employed on a continuous basis or infrequently, depending upon the system 10 in which it is used. Computation of the correction coefficients may be performed at a remote location, such as the calibration station 14, where human operators determine the commanded correction coefficients, or on the satellite 12 using a closed-loop feedback path between the local antenna 17 and each of the antenna element chains.

[0039] Thus, there has been described a management system 20 and calibration method 50 for use with a phased array antenna 21, 22 that increases its robustness to component changes or failures. The system and method employs a system level measurement of amplitude and phase, conducted during normal operation, to determine on an element by element basis, the tracking performance of individual chains 30 that form the antennas 21, 22. This amplitude and phase information is employed to compensate the each chain 30 for the measured error. The system 20 and method 50 measures the amplitude and phase of individual element chains 30 utilizing probe carriers. The required correction coefficients for each chain 30 are determined from the measured amplitude and phase data, and each individual element chain 30 is individually compensated to remedy the amplitude and phase errors. The system 20 and method 50 generates a probe carrier that is applied to each element chain 30 along with normal communication signal waveforms. The probe carrier is sufficiently small (narrow bandwidth, low power, or encoded) so that it does not significantly degrade

syst m operation. The relative amplitude and phase of the probe carrier, as applied to an element chain 30, is measured. By switching the probe carrier in time sequence between each chain 30, the differential amplitude and phase characteristics of each of the chains 30 is determined. This also serves to detect component failures in a chain 30. Each chain 30 includes commandable amplitude and phase weighting networks 34, 35. Once the differential amplitude and phase tracking characteristics of the antenna 21, 22 are characterized, th individual weighting networks 34,35 are commanded to settings that compensate for the measured values.

[0040] Thus there has been described a new and improved management system and antenna calibration method for use with a phased array communication system that uses the system to solve component problems occurring in the transmit and receive antenna arrays. It is to be understood that the above-described embodiments are merely illustrative of some of the many specific embodiments that represent applications of the principles of the present invention. Clearly, numerous and other arrangements can be readily devised by those skilled in the art without departing from the scope of the invention.

Claims

1. A phased array antenna management system for use with a phased array communication system (10) comprising

   a phased array antenna (21, 22) that includes a plurality of antenna element chains (30), wherein each chain (30) comprises a phase adjustment network (35), an amplifier (36), a filter (37), and an antenna element (27, 28),
   a probe carrier source (32; 32') for generating a probe carrier signal that is processed by each antenna element chain (30), and
   means for generating and applying corrective weighting coefficients (ΔA, $\Delta \Phi$) to the phase adjustment networks (35),

   characterized in that

   said probe carrier source (32, 32') generates a non-interfering carrier signal,
   the communication system (10) comprises transmit and receive phased array antennas (21, 22) that each include a plurality of antenna element chains (30),
   each chain (30) includes additionally an amplitude adjustment network (34) and has a desired amplitude and phase relationship with respect to the other chains (30) of each of the antennas (21, 22),
   the probe carrier signal is orthogonally processed by each antenna element chain (30),
   determining means (40) determine the amplitude and phase produced by each chain (30) of the transmit and receive phased array antennas (21, 22) in response to the probe carrier signal, for comparing the amplitude and phase produced by each chain (30) to the desired amplitude and phase relationship for each chain (30), and for generating the corrective weighting coefficients (ΔA, $\Delta \Phi$) for chains (30) that do not have the desired amplitude and phase relationship; and
   applying means (18) apply the corrective weighting coefficients (ΔA, $\Delta \Phi$) to the amplitude and phase adjustment networks (34, 35) of each chain (30) of the transmit and receive phased array antennas (21, 22) to produce the desired amplitude and phase relationship therebetween.

2. The phased array antenna management system of claim 1, **characterized in that** the probe carrier source (32) comprises a commutator switch (33) for sequentially processing the probe carrier signal through each antenna element chain (30).

3. The phased array antenna management system of claim 1 or claim 2, **characterized in that** the probe carrier source (32) comprises a signal source modulated by a code generator for generating orthogonal probe carrier signals for processing by each antenna element chain (30).

4. The phased array antenna management system of any of claims 1 - 3, **characterized in that** the means (40) for determining the amplitude and phase produced by each chain (30) comprises:

   a calibration station (14) remotely located from the transmit and receive phased array antennas (21, 22) and an antenna (46), a receiver (41), and amplitude and phase determining means (42) for detecting the amplitude and phase produced by each chain (30); and
   a communications link (15) coupled between the transmit and receive phased array antennas (21, 22) and

the calibration station (14).

5. The phased array antenna management system of any of claims 1 - 3, **characterized in that** the means (40) for determining the amplitude and phase produced by each chain (30) comprises a local antenna (17), a receiver (41'), and amplitude and phase determining means (42') for detecting the amplitude and phase produced by each chain (30).

6. A method of calibrating a phased array antenna (21, 22) of a phased array communication system (10), the phased array antenna (21, 22) having a plurality of antenna element chains (30), comprising the steps of:

   processing (51-55; 61-64) a probe carrier through the antenna (21, 22) and
   generating and applying (58; 67) corrective weighting coefficients (ΔA, ΔΦ) to the antenna element chains (30),

   characterized by

   the communication system (10) having transmit and receive phased array antennas (21, 22), each of the antenna element chains (30) having a desired amplitude and phase relationship with respect to each other,
   orthogonally processing (51-55; 61-64) a non-interfering probe carrier through each antenna chain (30) of the transmit and receive antennas (21, 22);
   comparing (56; 65) the respective phases and amplitudes of the processed probe carriers to provide a map of differential amplitudes and phases of each antenna chain (30) of the respective transmit and receive antennas (21, 22);
   generating (57; 66) the corrective weighting coefficients (ΔA, ΔΦ) for chains (30) that do not have the desired amplitude and phase relationship; and
   applying (58; 67) the corrective weighting coefficients (ΔA, ΔΦ) to each chain (30) of the transmit and receive antennas (21, 22) to produce the desired amplitude and phase relationship therebetween.

Patentansprüche

1. System zur Steuerung einer phasengesteuerten Gruppenantenne zur Verwendung in einem phasengesteuerten Kommunikationssystem (10), mit

   einer phasengesteuerten Gruppenantenne (21, 22), die eine Vielzahl von Antennenelementen (30) aufweist, wobei jede Kette (30) ein Phaseneinstellnetzwerk (35), einen Verstärker (36), ein Filter (37) und ein Antennenelement (27, 28) aufweist,

   einer Meßträgersignalquelle (32; 32') zur Erzeugung eines Meßträgersignals, das von jeder Antennenelementkette (30) verarbeitet wird und

   einem Mittel zum Erzeugen und Anwenden korrigierender Gewichtungskoeffizienten (ΔA, ΔΦ) bei den Phaseneinstellnetzwerken (35), **dadurch gekennzeichnet, daß** die Meßträgersignalquelle (32; 32') ein nicht störendes Trägersignal erzeugt,

   das Kommunikationssystem (10) phasengesteuerte Sende- und Empfangs-Gruppenantennen (21, 22) aufweist, deren jede eine Vielzahl von Antennenelementketten (30) umfaßt,

   jede Kette (30) zusätzlich ein Amplitudeneinstellnetzwerk (34) aufweist und eine gewünschte Amplituden und-Phasenbeziehung mit Bezug auf die anderen Ketten (30) jeder der Antennen (21, 22) besitzt,

   das Meßträgersignal orthogonal von jeder Antennenelementkette (30) verarbeitet wird,

   ein Bestimmungsmittel (40) die Amplitude und Phase bestimmt, die von jeder Kette (30) der phasengesteuerten Sende- und Empfangsantennen (21, 22) in Antwort auf das Meßträgersignal erzeugt wird, um die von jeder Kette (30) erzeugte Amplitude und Phase mit der gewünschten Amplituden- und Phasenbeziehung für jede Kette (30) zu vergleichen, und um die korrigierenden Gewichtungskoeffizienten (ΔA, ΔΦ) für Ketten (30) zu erzeugen, die nicht die gewünschte Amplituden und Phasenbeziehung besitzen; und

ein Beaufschlagungsmittel (18) die Amplituden- und Phaseneinstellnetzwerke (34, 35) jeder Kette (30) der phasengesteuerten Sende- und Empfangsantennen (21, 22) mit den korrigierenden Gewichtungskoeffizienten (ΔA, ΔΦ) beaufschlagt, um die gewünschte Amplituden- und Phasenbeziehung zwischen diesen herzustellen.

2. System zur Steuerung der phasengesteuerten Antenne nach Anspruch 1, **dadurch gekennzeichnet, daß** die Meßträgersignalquelle (32) einen Umschalter (33) zur sequenziellen Verarbeitung des Meßträgersignals durch jede Antennenelementkette (30) aufweist.

3. System zur Steuerung einer phasengesteuerten Antenne nach Anspruch 1 oder 2, **dadurch gekennzeichnet, daß** die Meßträgersignalquelle (32) eine Signalquelle aufweist, die von einem Codegenerator moduliert wird, um orthogonale Meßträgersignale zur Verarbeitung durch jede Antennenelementkette (30) zu erzeugen.

4. System zur Steuerung einer phasengesteuerten Antenne nach einem der Ansprüche 1 bis 3, **dadurch gekennzeichnet, daß** das Mittel (40) zum Bestimmen der Amplitude und Phase, die von jeder Kette (30) erzeugt wird, aufweist:

   eine Kalibrierungsstation (14), die entfernt von den phasengesteuerten Sende- und Empfangs-Gruppenantennen (21, 22) und einer Antenne (46), einem Empfänger (41) und einem Amplituden- und Phasenbestimmungsmittel (42) zum Erfassen der Amplitude und Phase, die von jeder Kette (30) erzeugt werden, liegt; und

   eine Kommunikationsverbindung (15), die die phasengesteuerten Sende- und Empfangs-Gruppenantenne (21, 22) und die Kalibrierungsstation (14) verbindet.

5. System zur Steuerung einer phasengesteuerten Gruppenantenne nach einem der Ansprüche 1 bis 3, **dadurch gekennzeichnet, daß** das Mittel (40) zum Bestimmen der Amplitude und Phase, die von jeder Kette (30) erzeugt werden, eine lokale Antenne (17), einen Empfänger (41') und ein Amplituden- und Phasenbestimmungsmittel (42') zur Bestimmung der von jeder Kette (30) erzeugten Amplitude und Phase aufweist.

6. Verfahren zum Kalibrieren einer phasengesteuerten Gruppenantenne (21, 22) eines phasengesteuerten Kommunikationssystems (10), wobei die phasengesteuerten Gruppenantennen (21, 22) eine Vielzahl von Antennenelementketten (30) aufweisen, mit den Schritten:

   Verarbeiten (51-55; 61--64) eines Meßträgersignals durch die Antennen (21, 22) und

   Erzeugen und Anwenden (58; 67) von korrigierenden Gewichtungskoeffizienten (ΔA, ΔΦ) bei den Antennenelementketten (30),

   gekennzeichnet durch

   das Kommunikationssystem (10) mit phasengesteuerten Sende- und Empfangs-Gruppenantennen (21, 22), wobei jede der Antennenelementkette (30) eine gewünschte Amplituden- und Phasenbeziehung aufweist,

   orthogonales Verarbeiten (51-55; 61-64) eines nicht störenden Meßträgersignals **durch** jede Antennenkette (30) der Sende- und Empfangsantennen (21, 22);

   Vergleichen (56; 65) der jeweiligen Phasen und Amplituden der verarbeiteten Meßträgersignale, um eine Tabelle von Differenzamplituden und -phasen jeder Antennenkette (30) der jeweiligen Sende- und Empfangsantennen (21, 22) zu schaffen;

   Erzeugen (57; 66) der korrigierenden Gewichtungskoeffizienten (ΔA, ΔΦ) für Ketten (30), die nicht die gewünschte Amplituden- und Phasenbeziehung haben; und

   Beaufschlagen (58; 67) jeder Kette (30) der Sende- und Empfangsantennen (21, 22) mit den korrigierenden Gewichtungskoeffizienten (ΔA, ΔΦ), um die gewünschte Amplituden- und Phasenbeziehung zwischen diesen zu erzeugen.

R vendicati ns

1. Système de gestion d'antenne à groupement à déphasage pour l'utilisation avec un système de communication à groupement à déphasage (10) comprenant

   une antenne à groupement à déphasage (21, 22) qui comprend une pluralité de chaînes d'éléments d'antenne (30), dans laquelle chaque chaîne (30) comprend un réseau de réglage de phase (35), un amplificateur (36), un filtre (37), et un élément d'antenne (27, 28),
   une source de porteur de sonde (32; 32') pour générer un signal porteur de sonde qui est traité par chaque chaîne d'élément d'antenne (30), et
   des moyens pour générer et appliquer des coefficients de pondération correcteurs (ΔA, $\Delta\Phi$) aux réseaux de réglage de phase (35),

   caractérisé en ce que

   la source de porteur de sonde (32, 32') génère un signal porteur non brouilleur,
   le système de communication (10) comprend des antennes à groupement à déphasage d'émission et de réception (21, 22) incluant chacune une pluralité de chaînes d'éléments d'antenne (30),
   chaque chaîne (30) comprend en outre un réseau de réglage d'amplitude (34) qui a une relation d'amplitude et de phase désirée vis-à-vis des autres chaînes (30) de chacune des antennes (21, 22),
   le signal porteur de sonde est traité de façon orthogonale par chaque chaîne d'élément d'antenne (30),
   des moyens de détermination (40) déterminent l'amplitude et la phase produite par chaque chaîne (30) des antennes à groupement à déphasage d'émission et de réception (21, 22) en réponse au signal porteur de sonde, pour comparer l'amplitude et la phase produites par chaque chaîne (30) avec la relation d'amplitude et de phase désirée pour chaque chaîne (30), et pour générer les coefficients de pondération correcteurs (ΔA, $\Delta\Phi$) pour des chaînes (30) qui n'ont pas la relation d'amplitude et de phase désirée; et
   des moyens d'application (18) appliquent les coefficients de pondération correcteurs (ΔA, $\Delta\Phi$) aux réseaux de réglage d'amplitude et de phase (34, 35) de chaque chaîne (30) des antennes à groupement à déphasage d'émission et de réception (21, 22), pour produire la relation d'amplitude et de phase désirée entre elles.

2. Système de gestion d'antenne à groupement à déphasage selon la revendication 1, **caractérisé en ce que** la source de porteur de sonde (32) comprend un commutateur (33) pour traiter séquentiellement le signal porteur de sonde en le faisant passer par chaque chaîne d'élément d'antenne (30).

3. Système de gestion d'antenne à groupement à déphasage selon la revendication 1 ou la revendication 2, **caractérisé en ce que** la source de porteur de sonde (32) comprend une source de signal modulée par un générateur de code pour générer des signaux porteurs de sonde orthogonaux pour le traitement par chaque chaîne d'élément d'antenne (30).

4. Système de gestion d'antenne à groupement à déphasage selon l'une quelconque des revendications 1 - 3, **caractérisé en ce que** les moyens (40) pour déterminer l'amplitude et la phase produites par chaque chaîne (30) comprennent :

   une station d'étalonnage (14) située à distance des antennes à groupement à déphasage d'émission et de réception (21, 22), et une antenne (46), un récepteur (41) et des moyens de détermination d'amplitude et de phase (42) pour détecter l'amplitude et la phase produites par chaque chaîne (30); et
   une liaison de communication (15) couplée entre les antennes à groupement à déphasage d'émission et de réception (21, 22) et la station d'étalonnage (14).

5. Système de gestion d'antenne à groupement à déphasage selon l'une quelconque des revendications 1 - 3, **caractérisé en ce que** les moyens (40) pour déterminer l'amplitude et la phase produites par chaque chaîne (30) comprennent une antenne locale (17), un récepteur (41') et des moyens de détermination d'amplitude et de phase (42') pour détecter l'amplitude et la phase produites par chaque chaîne (30).

6. Procédé d'étalonnage d'une antenne à groupement à déphasage (21, 22) d'un système de communication à groupement à déphasage (10), l'antenne à groupement à déphasage (21, 22) ayant une pluralité de chaînes d'éléments d'antenne (30), comprenant les étapes suivantes :

on traite (51-55; 61-64) un porteur de sonde en le faisant passer par l'antenne (21, 22) et
on génère et on appliqu (58; 67) des coefficients de pondération correcteurs (ΔA, ΔΦ) aux chaînes d'éléments d'antenne (30),

caract´risé en ce que

le système de communication (10) comporte des antennes à groupement à déphasage d'émission et de réception (21, 22), chacune des chaînes d'éléments d'antenne (30) ayant une relation d'amplitude et de phase désirée vis-à-vis de chacune des autres,
on traite de façon orthogonale (51-55; 61-64) un porteur de sonde non brouilleur en le faisant passer par chaque chaîne d'antenne (30) des antennes d'émission et de réception (21, 22);
on compare (56; 65) les phases et les amplitudes respectives des porteurs de sonde traités pour produire un plan d'amplitudes et de phases différentielles de chaque chaîne d'antenne (30) des antennes d'émission et de réception (21, 22) respectives;
on génère (57; 66) les coefficients de pondération correcteurs (ΔA, ΔΦ) pour des chaînes (30) qui n'ont pas la relation d'amplitude et de phase désirée; et
on applique (58; 67) les coefficients de pondération correcteurs (ΔA, ΔΦ) à chaque chaîne (30) des antennes d'émission et de réception (21, 22) pour produire la relation d'amplitude et de phase désirée entre elles.

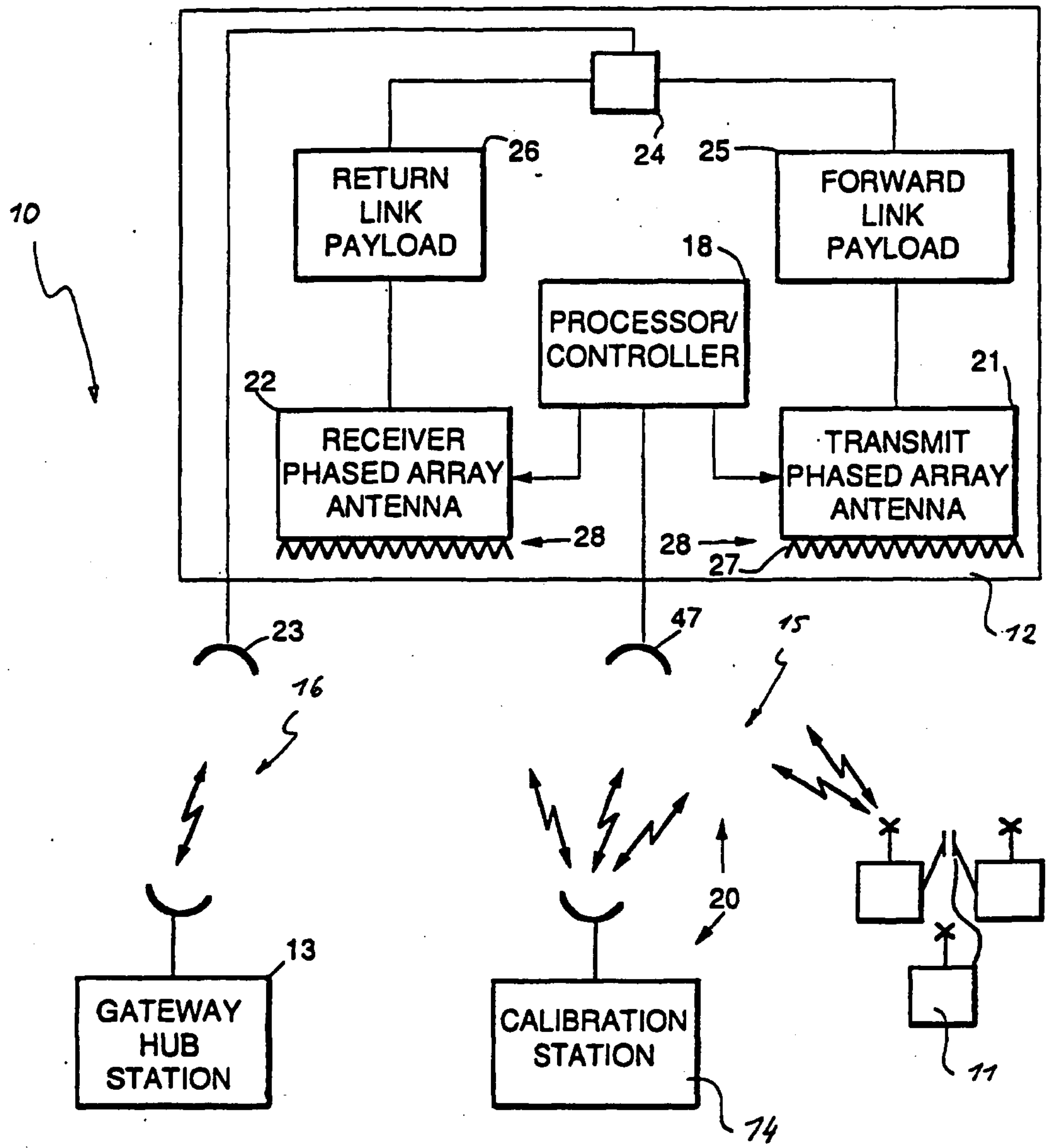
RETURN LINK PAYLOAD
FORWARD LINK PAYLOAD
PROCESSOR/ CONTROLLER
RECEIVER PHASED ARRAY ANTENNA
TRANSMIT PHASED ARRAY ANTENNA
GATEWAY HUB STATION
CALIBRATION STATION
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FIG. 1.

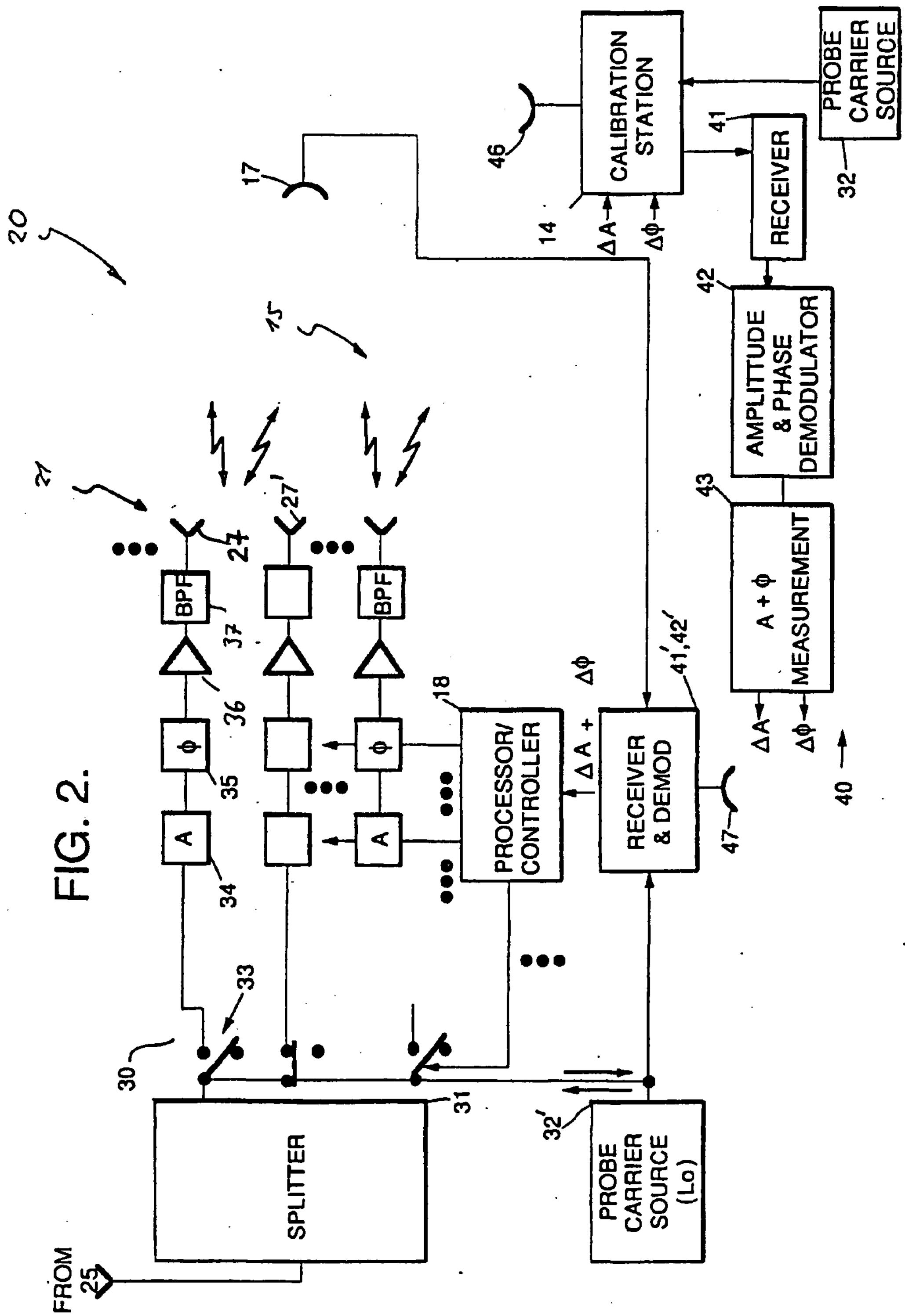
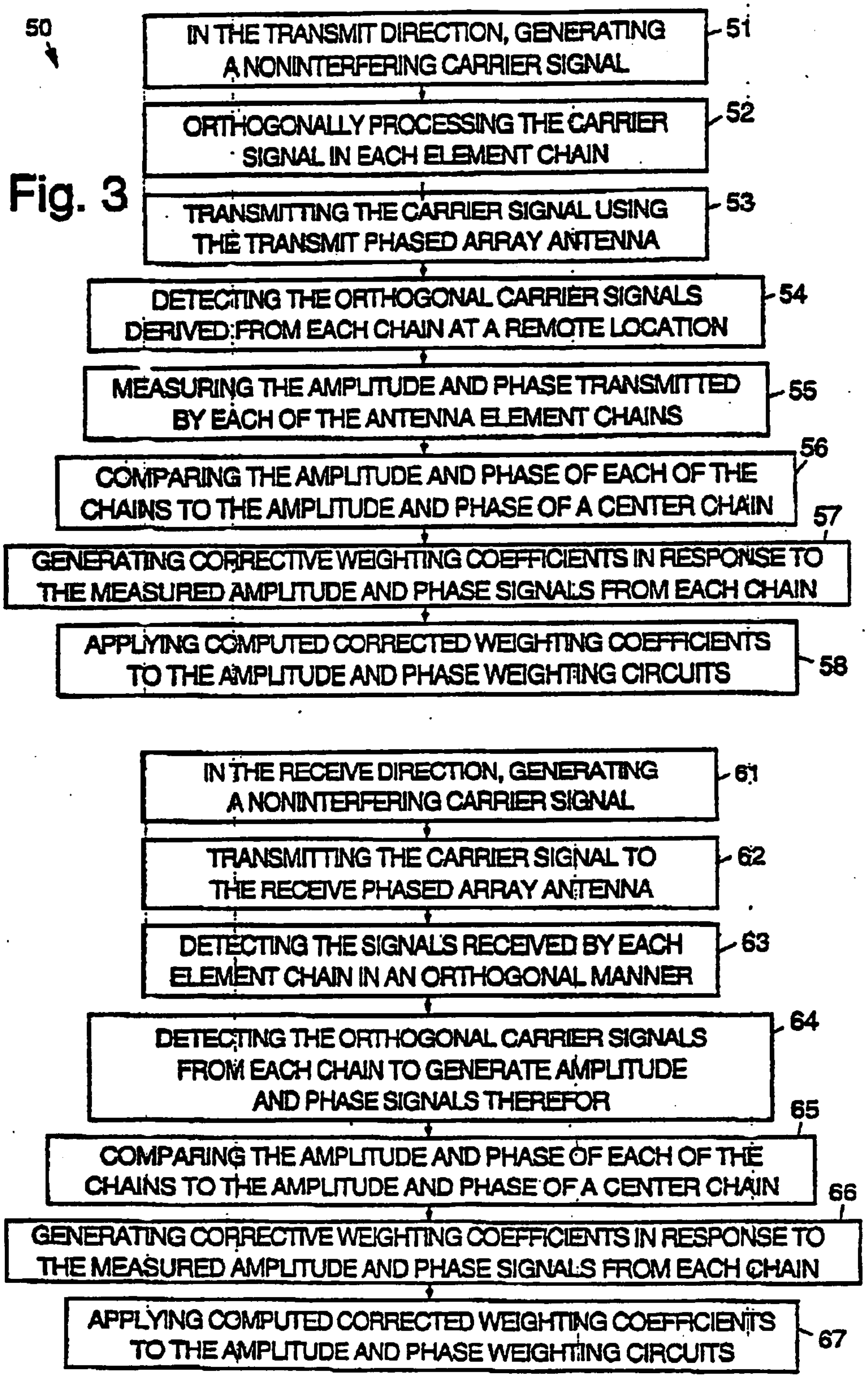

FROM 25
SPLITTER
PROBE CARRIER SOURCE (Lo)
PROCESSOR/ CONTROLLER
RECEIVER & DEMOD
CALIBRATION STATION
RECEIVER
PROBE CARRIER SOURCE
AMPLITUDE & PHASE DEMODULATOR
A + Φ MEASUREMENT
BPF
A
Φ
ΔA
ΔΦ

FIG. 2.


50
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TRANSMITTING THE CARRIER SIGNAL USING THE TRANSMIT PHASED ARRAY ANTENNA
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MEASURING THE AMPLITUDE AND PHASE TRANSMITTED BY EACH OF THE ANTENNA ELEMENT CHAINS
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Fig. 3